Signal-to-noise ratio

By Harold Kinley

One of the most fundamental principles in radio is that of signal-to-noise ratio (SNR) at various stages of a receiver chain. Factors such as receiver noise figure, antenna site noise, transmission line attenuation, antenna gain and directivity, transmitter output power and propagation all play a major role in determining the ultimate SNR at the input to a receiver. The noise figure of the receiver *might* play a major role in the final SNR at the *audio output* of the receiver. Let's examine how some of these factors affect the SNR at the receiver.

SNR can be defined by the simple mathematical expression shown below:

$$\frac{\text{Signal}}{\text{Noise}}$$

From this simple mathematical expression, it is clear that to improve the SNR we must *increase* the signal level, *reduce* the noise level or do both. Often, neither is easy, nor simple, to achieve.

Noise figure

The noise figure of a receiver may or may not have a significant impact on how the receiving system performs at a particular location. Let's look at the equivalent noise input to a receiver. First, let's take a 50Ω resistor and calculate the amount of noise voltage (E_n) at the open-circuited output terminals of the resistor. The formula for calculating this is:

$$E_n = \sqrt{4kTBR}$$

The k represents a constant of 1.38×10^{-23}. The T represents temperature, in degrees Kelvin. (Usually, 290°K is used for the temperature. This is equivalent to about 63°F, or 17°C.)

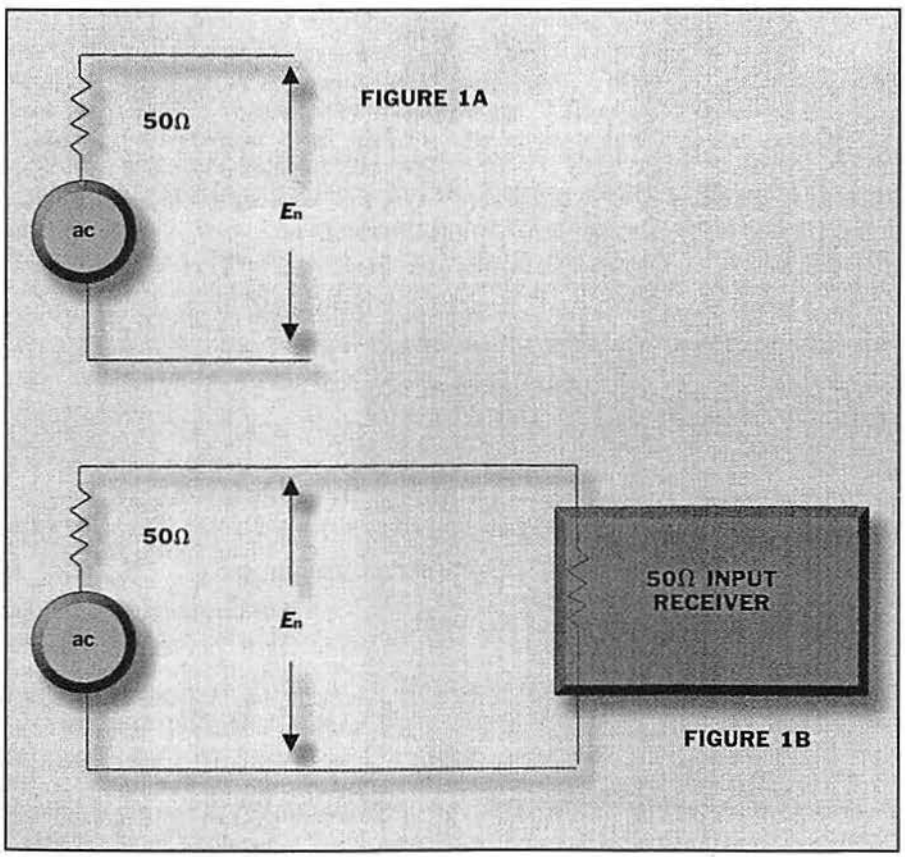

Figure 1A. The noise generated in the 50Ω resistor is represented as a generator in series with a 50Ω resistor. The open-circuit noise voltage, E_n, appears across the output terminals. Figure 1B. The resistor is connected across the receiver with a 50Ω input impedance. Only half of the noise voltage generated in the resistor appears across the input to the receiver because of the voltage divider action.

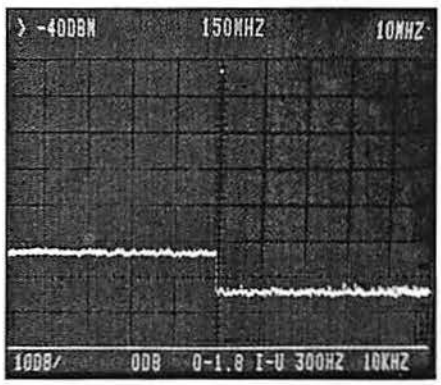

Photo 1. This spectrum analyzer display demonstrates that noise level is a function of the bandwidth of the receiver. Here, as the sweep was moving across the screen, the resolution bandwidth was switched from 100kHz to 10kHz. As shown on the screen, the noise level dropped by 10dB (see middle of screen).

B represents bandwidth in hertz, and R represents resistance in ohms.

The noise voltage in a 1Hz bandwidth would be:

$$\sqrt{4\times1.38\times10^{-23}\times290\times1\times50}$$
$$=8.9465076\times10^{-10}$$
$$=0.00089465076\mu V$$

Figure 1 at the left represents the resistor noise voltage by using a 50V signal generator. In Figure 1A, the output is open-circuited. In Figure 1B, the resistor is connected across the input to a receiver with a 50V input impedance. The noise voltage appearing across the receiver input is half the open-circuited noise voltage. Thus, the noise voltage across the receiver input is 0.000447325mV. This is equivalent to 2174dB, which is an important figure to remember. It means that in a 50V impedance, the noise floor at the input to a receiver with a noise figure of 0dB in a 1Hz bandwidth is 2174dBm. If we increase the bandwidth of the receiver by a factor of 10, then the noise floor increases by 10dB to 2164dBm. Compared to a bandwidth of 1Hz, the correction factor for other bandwidths is:

$$N = 10\log B$$

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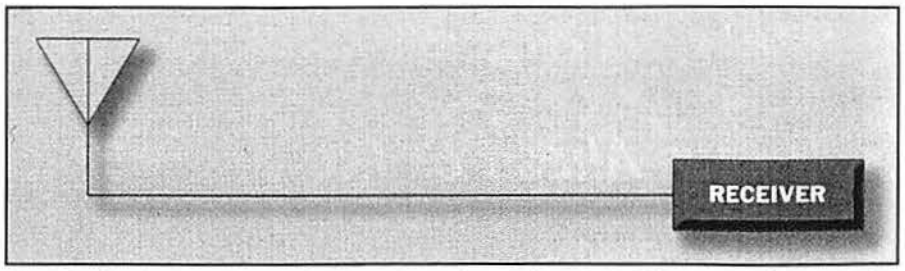
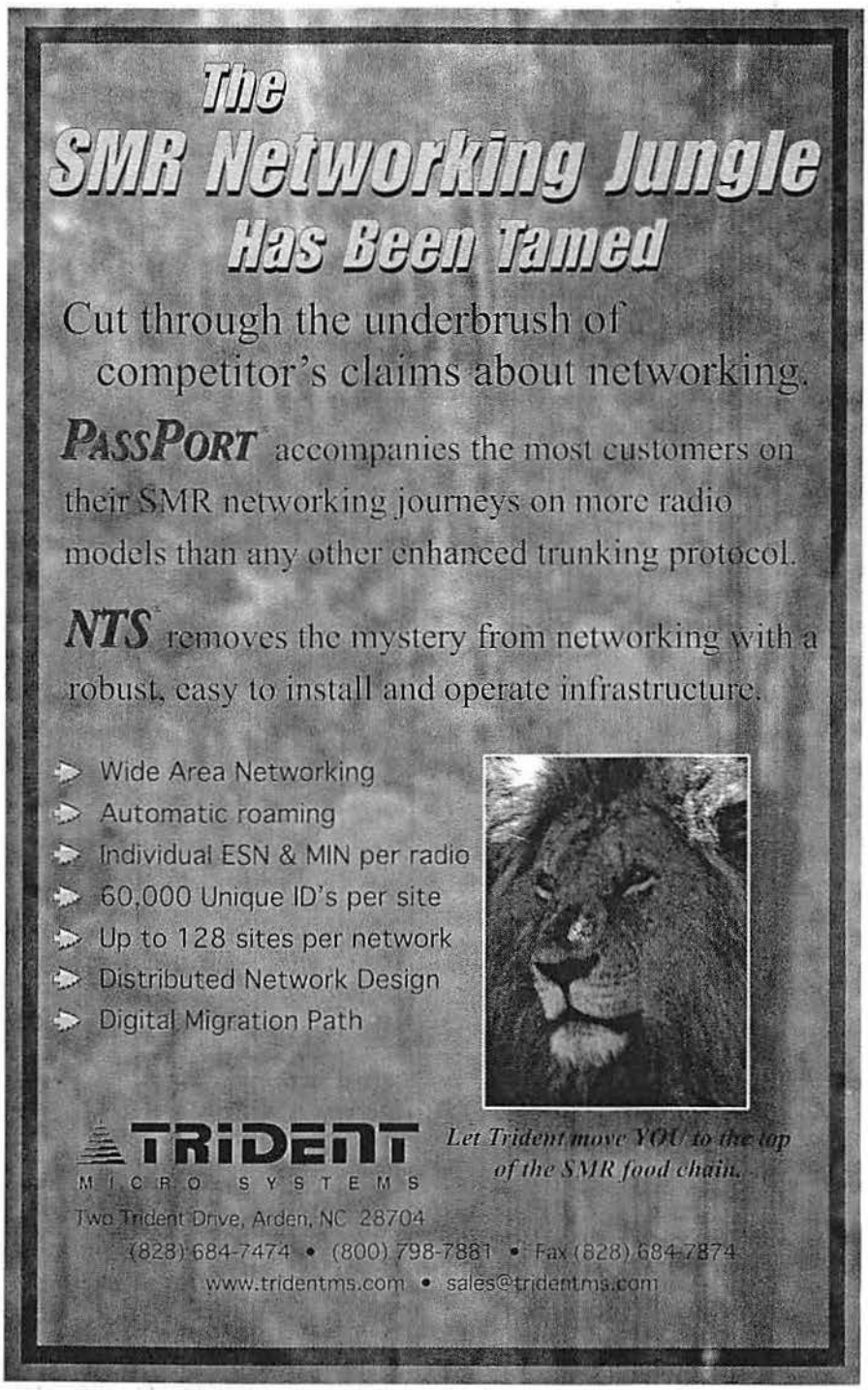


Figure 2. A typical receiver chain. The antenna is a unity-gain (0dBd) type. The transmission line has a 2dB loss. The receiver has a sensitivity of 0.3μV, or −117dBm. The noise floor of the receiver is −121dBm, making the receiver noise figure 11.24dB.

where N is the noise floor correction in decibels for bandwidth and B is the bandwidth in hertz. (See Photo 1 on page 18.)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For a typical, narrowband (±5kHz deviation) FM receiver, the bandwidth would be about 15kHz. The correction factor for 15kHz would be 10log15,000, or 41.76dB. Thus, for a receiver with a noise figure of 0dB, the noise floor would be −174 + 41.76, or −132.24dB. Again, this is for a receiver with a noise figure of 0dB. The noise floor of a typical, narrowband FM receiver is about 4dB below the 12dB SINAD sensitivity of the receiver. For example, suppose the 12dB SINAD sensitivity of the receiver is 0.3μV, or −117dBm. Then, the noise floor of the receiver is −121dBm.

Because this is 11.24dB worse than a receiver with a 0dB noise figure [−121dBm − (−132.24dBm)], this receiver is said to have a noise figure of 11.24dB.

It is interesting to note that once the RF input signal level is increased by about 4dB above the noise floor of the receiver, the audio output of the receiver can produce 12dB SINAD. (This was checked against several references and with a design engineer. It is a questionable point to ponder, but the experts say it is true.)

Remember that the receiver noise figure *may* or *may not* have a significant impact on how the *receiving system* performs at a particular site. "Receiving system" means all of the components that make up the receiver chain. The receiver itself will be considered as a single component of the chain—not broken down into subsystems such as mixer, IF amplifier, etc. A few examples will illustrate, using various situations and receiver chains.

Example 1

Figure 2, above left, shows a typical base station installation that is simple and straightforward. The antenna is a unity-gain (0dBd) type. The transmission line has a loss of 2dB. The receiver sensitivity is 0.3μV. The noise voltage induced into the antenna from surrounding (near or far) noise sources is at a level of −125dBm. The desired signal voltage appearing across the antenna terminals at the coaxial cable connection is 1μV. Converting the 1μV signal to decibels referenced to 1mW (dBm) yields a signal level of −107dBm.

The signal from the antenna is attenuated 2dB by the transmission line and is reduced to a level of −109dBm at the receiver input. The noise induced into the antenna is also attenuated 2dB by the transmission line and appears at the receiver input at a level of −127dBm. As long as the noise contributed by the

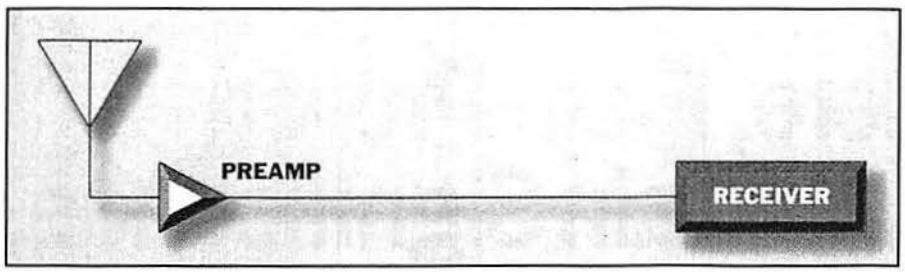


Figure 3. This is the same setup as in Figure 2, except that a tower-top preamplifier has been added. The preamplifier has a noise figure of 2dB and a gain of 15dB.

antenna is several decibels greater (at the receiver input) than the receiver noise floor, the antenna-contributed noise will be the predominant noise, and the receiver noise can be ignored for practical purposes. In this case, the receiver noise floor is −121dBm. So the noise contributed by the antenna and present at the receiver input is 6dB *below* the level of the receiver noise floor. In this case, the receiver noise is the predominant noise.

The total noise at the receiver input can be determined by finding the *root-sum-square* of the *antenna-contributed noise* and the *receiver-contributed noise.* Because the antenna-contributed noise at the receiver input is −127dBm, or 0.1μV, and the receiver-contributed noise is −121dBm, or 0.2μV, the total noise at the receiver input is:

$$\sqrt{0.1^2 + 0.2^2} = \sqrt{0.05} = 0.2236\mu V .$$

A level of 0.2236μV is equal to −120dBm. So, the SNR at the receiver input is 11dB [−109 − (−120)]. If the minimum required SNR is 10dB, then this situation would just meet the minimum requirements.

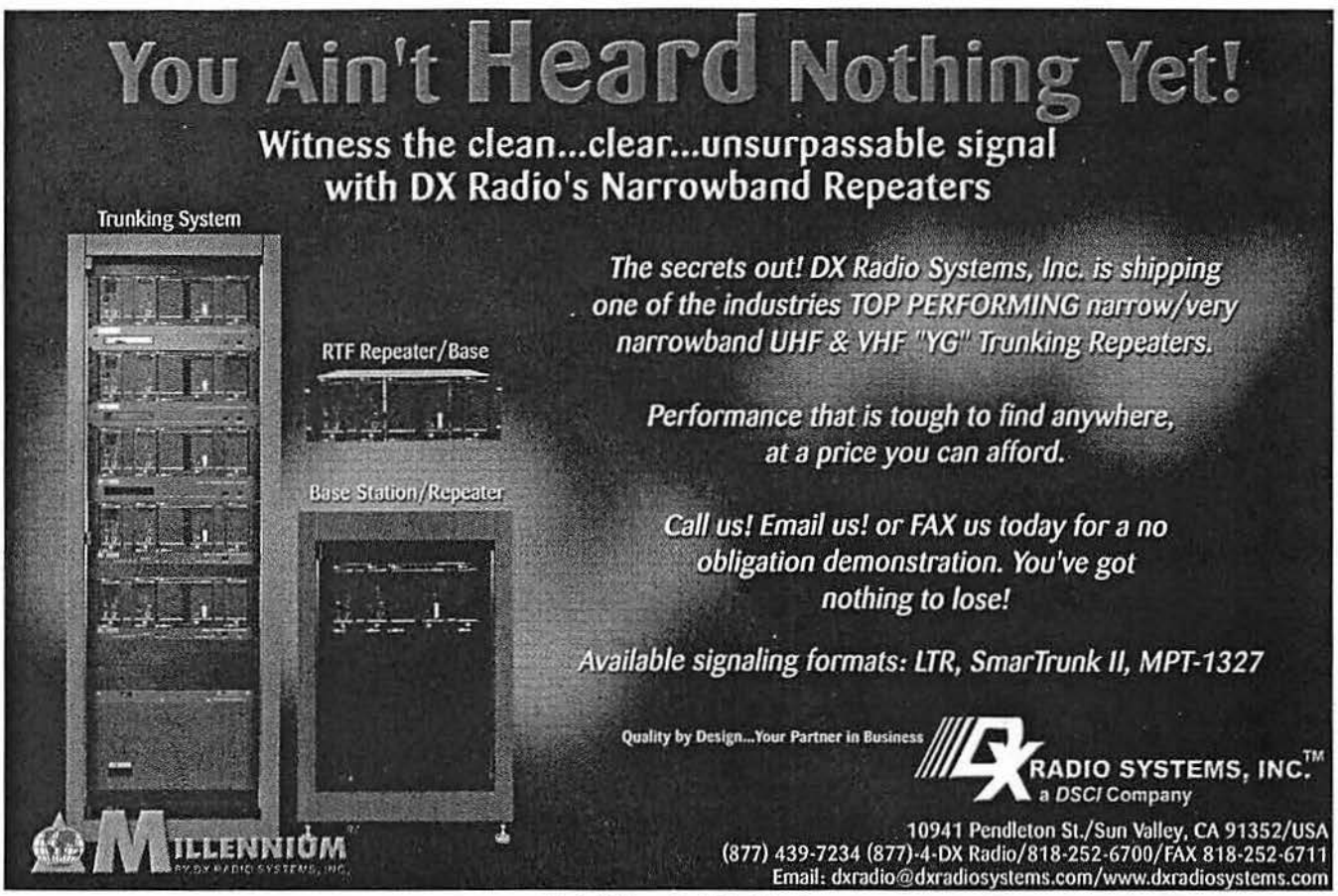
Example 2

On certain days, due to poor propagation conditions, the signal at the antenna terminals drops by about 5dB to a level of −112dBm. Assuming the noise level remains the same at the antenna site, this will produce a signal level of −114dBm at the receiver input and a noise level (antenna-contributed) of −127dBm. From the calculations in the first example, we know that the noise level at the receiver input is −120dBm because the noise level at the antenna did not change.

Now, the signal level at the receiver input will be −114dBm, resulting in a SNR of 6dB at the receiver input. This is far below the required SNR and will produce a noisy signal at the audio output. What can be done to improve the situation? It depends on several factors. If this is a fixed point-to-point link between two base stations, then the power of the transmitters might be increased. This would require a quadrupling of the transmitter power on each end (assuming both ends are affected equally by deteriorating propagation conditions). Increasing antenna gains, or using directional antennas, might provide the necessary increase in signal level. What about a tower-top preamplifier at the site? In the next example we will add a preamplifier and calculate the results.

Example 3

With everything else the same as in the previous example, we add a tower-top preamplifier to the receiving chain, as shown in Figure 3 above. The noise figure of the preamplifier is 2dB and the gain is 15dB. Let's calculate the results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using the degraded signal of the second example. Again, the signal at the antenna terminals is −112dBm and the noise level induced into the antenna is −125dBm. At the preamplifier output, the signal level is −97dBm and the antenna-contributed noise level is −110dBm. At this point, the SNR is 13dB. At the receiver input, the signal is −99dBm and the antenna-contributed noise is −112dBm. Because the antenna-contributed noise at the receiver input is 9dB above the receiver-contributed noise, the receiver noise can be ignored for practical purposes.

The resultant SNR at the receiver input is 13dB, which is 3dB above the minimum required SNR. Thus, the tower-top preamplifier improved the situation in this particular case, based on the SNR alone. This does not take into account any possible problems associated with strong intermod-causing signals or other strong-signal problems that might cause receiver desensitization. These must also be considered when deciding whether or not a tower-top preamplifier might be beneficial to the overall receiving system.

You might have noticed that we ignored the 2dB noise figure of the preamplifier because the SNR at the preamplifier output was the same (13dB) as at the input. We chose to ignore the noise figure of the preamplifier because its equivalent noise input would be less than −130dBm, and the antenna-contributed noise is several decibels higher: −125dBm. Although the 2dB noise figure of the preamplifier would have produced a lower SNR at the output of the preamplifier, it would not have been as much as 2dB.

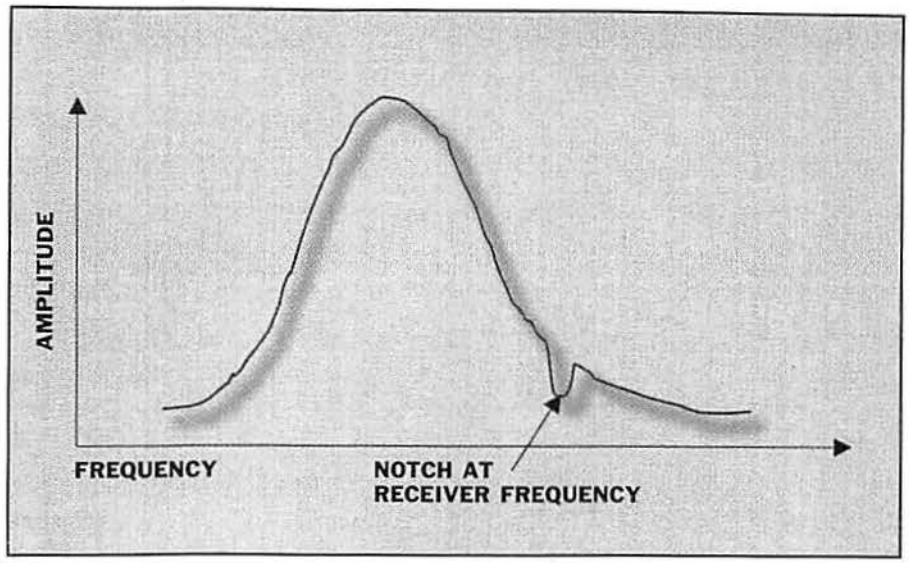

Figure 4. Transmitter sideband noise extends above and below the carrier frequency. Here, a notch filter has been installed on a nearby transmitter to notch out the noise falling within the offended receiver's passband. The result lowers the noise level at the offended receiver, thus improving the signal-to-noise ratio.

Example 4

Suppose that the signal level is good, but the noise level on the site has increased such that the SNR is seriously degraded. This will cause the weaker signals to be lost in noise and to become

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unreadable. One typical cause of such an increase in noise level is transmitter sideband noise. Such noise occupies a wide bandwidth and can seriously impair "effective" receiver sensitivity. Nothing can be done at the affected receiver to mitigate the problem. The solution lies with the offending transmitter.

Suppose that transmitter sideband noise is increasing the noise level at the antenna terminals from −125dBm to −110dBm. This means that the SNR at the antenna terminals will be degraded by 15dB. If the offending transmitter is lower in frequency than the affected receiver frequency, a low-pass notch filter should be used at the offending transmitter. If the frequency of the offending transmitter is above that of the affected receiver, use a high-pass notch filter.

In Figure 4 on page 23, the offending transmitter's frequency is below that of the affected receiver. A low-pass notch filter has been placed on the offending transmitter. The sideband energy at the frequency of the affected receiver is "notched" out of the sideband noise spectrum. The notch filter can be placed at the output of the transmitter. However, because most of the sideband noise originates within the exciter, a notch filter is placed between the exciter and the power amplifier, or intermediate power amplifier. Reducing the sideband noise with the notch filter should improve the S/N ratio at the affected receiver.

Conclusions

If the ambient site noise at the receiver location were much higher than in the examples, the tower-top preamplifier would be of no benefit. It might do more harm than good. If the receiver system is a base-to-mobile operation, then increasing the antenna gain on each end might help, as long as the ambient site noise is fairly low. Increasing antenna gain at a high site noise location might not yield the expected results.

Changing an antenna from a quarter-wave whip located on a fender to a $^5/_8$-wave "gain" antenna located on the vehicle's roof might provide significant improvement in the SNR at the receiver. Using directional antennas can help in point-to-point communications and even in certain base-to-mobile applications, depending on the required coverage pattern and the location of major noise source(s) relative to the direction of desired coverage. For example, if a highly directional antenna is "looking" toward the noise source, the situation might show no improvement when compared to an omnidirectional antenna.

If the transmission line loss is high, then changing to a low-loss line might improve the SNR, but not if the ambient site noise is high. Using a more sensitive receiver might help at sites where the site noise is low, but not in high-noise locations. Changing a receiver sensitivity from 0.3μV to 0.2μV changes the receiver noise floor from −117dBm to −121dBm, an improvement of 4dB. However, this 4dB improvement might not show up in the final SNR at the receiver input—especially at high-noise locations. Careful planning and calculations should be done before making system changes in an attempt to increase the SNR of the receiver chain.

Until next time—*stay tuned!* ■

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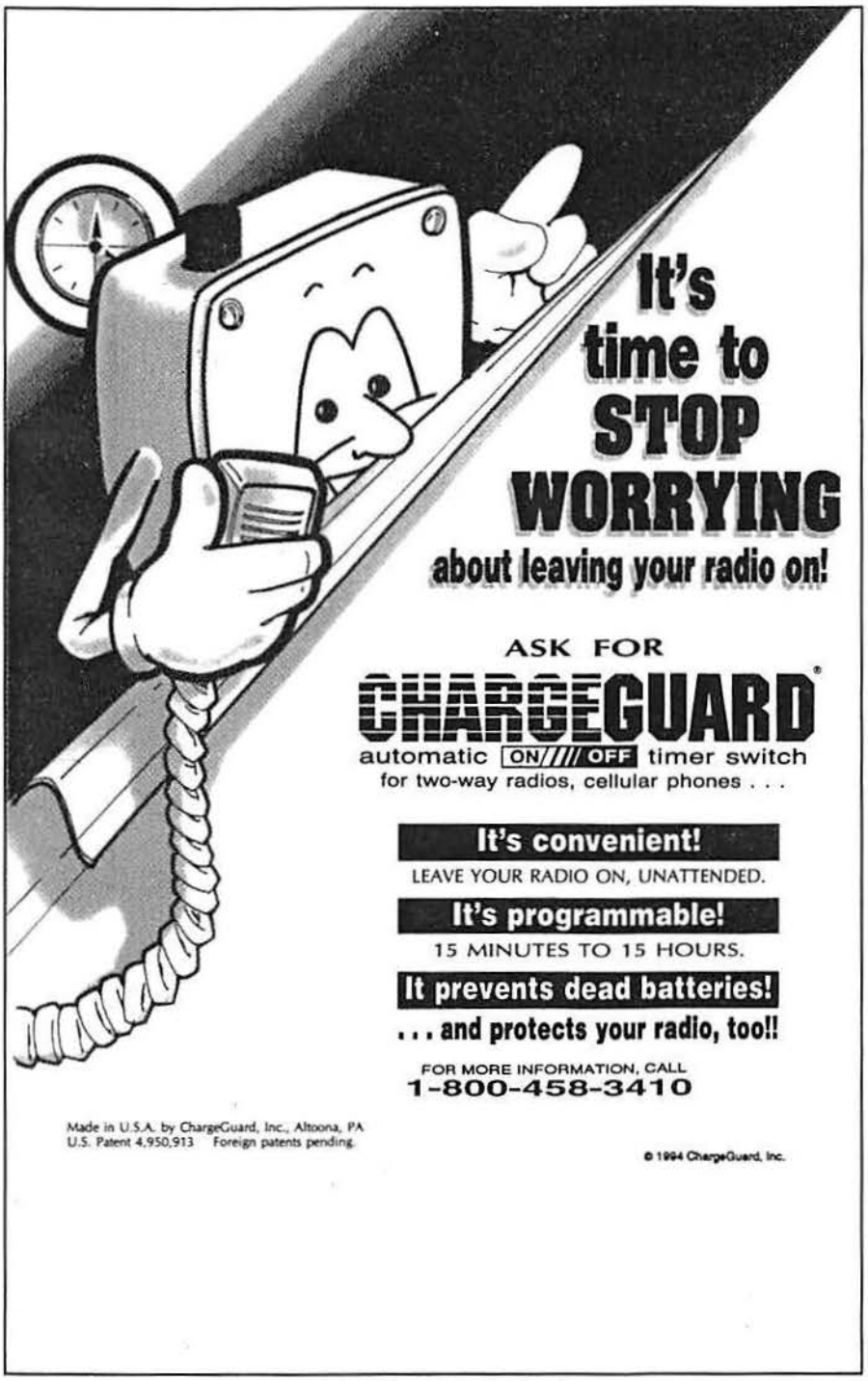
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